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(54) Optical transmission system including optical repeaters and regenerators.

(57) A long haul optical transmission system, e.g. for transoceanic applications, comprises a hybrid arrangement of a small number of optoelectronic regenerators (15) and a larger number of optical amplifiers (14). The arrangement permits the use of low cost fibre and, by using only a small number of regenerators, significantly reduces the system cost in comparison with an all repeatered system.

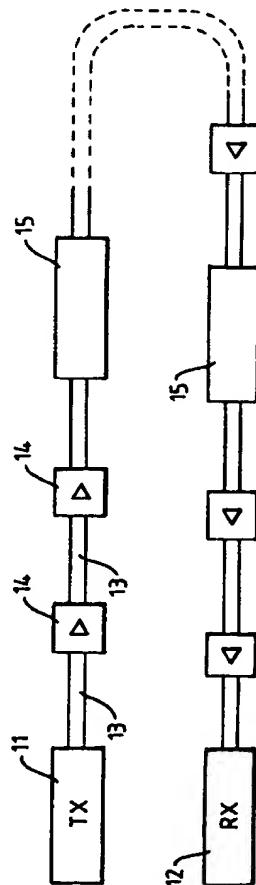


Fig.1.

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EP 0 579 401 A1

This invention relates to long-haul, e.g. transoceanic optical transmission systems.

#### BACKGROUND OF THE INVENTION

A conventional long-haul optical transmission system, e.g. a submarine system, incorporates an optical fibre cable provided at intervals with regenerators or repeaters whereby the transmitted signal is regenerated along the transmission path. Each repeater converts incoming optical signals to corresponding electrical signals which are then processed and retied prior to re conversion to optical signals for transmission along the next leg of the path.

As the regenerators have to perform a number of signal handling functions in addition to their basic regeneration or amplifying function, they are complex in construction and thus relatively costly. Indeed, the cost of the regenerators can represent a very significant proportion of the installed system cost.

Over recent years the problem of the system cost has been addressed in two ways. Firstly the system bit rate has been increased to allow the provision of more circuits and thus reduce the cost per circuit. This has been achieved by improvements in fibre quality and by advances in electric circuit development. Any future increases in bit rate are of course dependent on further such developments. Further, it is considered that there may be a fundamental limit of the bit rate beyond which it is not possible to provide effective transmission of signals. It is thought that for a long length of dispersive fibre this fundamental limit is of the order of 5 Gbit/sec.

An alternative approach that has recently been proposed is the use of optical amplifying systems. In such a system the conventional repeaters are replaced by linear optical amplifiers, e.g. erbium amplifiers. This results in a very significant reduction in the system costs as the amplifiers are relatively simple devices. However, the consequence of using linear amplifiers instead of repeaters is that impairments such as noise, distortion and non-linearity accumulate through the system. A particular problem is the dispersion of the fibre. Over a long-haul system the fibre dispersion must be very low to reduce the cumulative effects of chromatic dispersion.

The object of the present invention is to minimise or to overcome these disadvantages.

#### SUMMARY OF THE INVENTION

According to one aspect of the invention there is provided an optical transmission system, including an optical fibre transmission path, means for launching optical signals into said path, means for receiving optical signals from said path, and signal regeneration means disposed at intervals along said path, wherein said regeneration means comprises a plurality of opt-

ical amplifiers and a significantly smaller number of opto-electronic repeaters or regenerators dispersed substantially evenly between the optical amplifiers, the number of regenerators being sufficient to maintain the signal quality along the path.

According to another aspect of the invention there is provided an optical transmission subsystem, including an input regenerator, an output regenerator, an optical fibre transmission path therebetween, and a plurality of optical amplifiers disposed substantially evenly along said path, the gain of the optical amplifier and the spacing therebetween being selected so as to achieve a predetermined signal/noise ration at the input of the output regenerator.

The provision of a relatively small number of regenerators provides periodic 'clean-up' of the transmitted signals and thus allows transmission over long distances without the need to provide high cost low dispersion fibre.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:-

Fig. 1 is a schematic diagram of an optical transmission system incorporating both optical amplifiers and opto-electronic regenerators;

Fig. 2 illustrates the relationship between the regenerator spacing distance and the optical amplifier spacing distance of the system of Fig. 1;

Fig. 3 illustrates a basic subsystem from which the system of Fig. 1 may be constructed;

Fig. 4 illustrates the effects of forward error correction coding in the system of Fig. 1; and

Figs. 5 and 6 illustrate respective supervisory arrangements for the system of Fig. 1.

#### DESCRIPTION OF PREFERRED EMBODIMENT

Referring to Fig. 1, the system includes an optical transmitter 11 coupled to a remote receiver 12 via an optical fibre path 13, e.g. a submarine cable. The path 13 incorporates a number of linear optical amplifiers 14, e.g. erbium amplifiers disposed at regular intervals along the path. The amplifiers 14 may comprise each a length of amplifying fibre that is pumped by a laser. The system further includes a number of repeaters or regenerators 15 disposed at intervals along the path. For clarity Fig. 1 shows only a single optical path between the regenerators 15, but it will be appreciated that this path will in general comprise a number of optical fibres each having its own concatenated series of amplifiers. Typically there are six fibre paths, but this number is of course not critical. Such an arrangement provides both a high traffic capacity and a facility for routing around faults. This latter facility is not available in a conventional amplified

system. The number of regenerators 15 is significantly less than that of the amplifiers 14, there being typically one repeater 15 for every 7 to 10 amplifiers. For transatlantic distances we would require about 10 regenerators and between 70 and 100 amplifiers.

It will be appreciated that a signal that is repeatedly amplified by a number of linear amplifiers becomes degraded by the cumulative effects of e.g. noise and optical dispersion. The latter effect causes broadening of the signal pulses. The purpose of the repeaters 15 is thus periodically to reshape and retransmit the signal to overcome these cumulative effects. The repeaters may comprise '3R' repeaters which convert received optical signals into corresponding electrical signals. These electrical signals are then reshaped and retimed before being retransmitted as regenerated optical signals. In some applications retiming of the signals may be dispensed with as will be discussed below.

The amplifier/repeater hybrid arrangement described above has important and unexpected advantages over conventional non-hybrid systems. Firstly, it allows a significant reduction in the cost of the optical fibre employed in comparison with an all-amplifier system. As the transmitted signal is regenerated at regular intervals the effects of fibre dispersion are much reduced and it is thus possible to employ relatively low cost and low specification fibre. This contrasts with the high cost low dispersion fibres that are considered essential for use in all-amplifier systems. Secondly, the use of regenerators allows a considerable increase in the spacing between amplifiers when compared with an all amplifier system. This effect is illustrated in Fig. 2 which shows the relationship between amplifier spacing and unrepeated transmission distance for transmission bit rates of 2.5Gbit/s, 5 Gbit/s and 10 Gbit/s. As can be seen from Fig. 2, as the unregenerated space increases, the distance between amplifiers decreases, this effect being most pronounced at high bit rates. For example, a long haul system 6000Km in length would require an amplifier spacing of only 45Km for a bit rate of 5 Gbit/s in the absence of any regeneration. The incorporation of a small number of regenerators, e.g. one regenerator at every 1000Km, to provide a hybrid system, allows the spacing between amplifiers to be increased e.g. to about 125Km thus resulting in a significant cost saving. Thirdly, the relatively small number of regenerators permits the introduction of wavelength division multiplexing. This can significantly increase the effective capacity of the system. The provision of wavelength division multiplexing in a conventional system with a relatively large number of regenerators is not economically feasible as the total system cost of providing, in each regenerator, circuitry for each wavelength would then be prohibitive.

In addition, as discussed above the provision of regenerators provides a facility for routing around

system faults. Where one amplified fibre path between two regenerators become defective, e.g. as a result of a fibre break or an amplifier failure, the traffic previously carried on that path can be rerouted to one or more of the other fibre paths between the regenerators. This provides a significant increase in system reliability in comparison with an equivalent all-amplifier system.

By way of example the design of a hybrid system 10 will be discussed with particular reference to Fig. 3 which illustrates one amplified span or path of total length L between two regenerators (15a, 15b). Each optical amplifier (14) in the path is assumed to have a gain G and an optimum power output P<sub>1</sub>. The system is designed to provide a bit error rate less than a predetermined value.

In the amplifier path of Fig. 3, the bit error rate is determined by the signal/noise ratio P/N at the input of the regenerator 15b. It is assumed that spontaneous noise N<sub>s</sub> is present at the input of each amplifier. For each amplified section this spontaneous noise is increased by the amplifier gain G and is decreased by the fibre loss 1/G. The spontaneous noise thus increases linearly and the total noise N at the input of 25 the repeater 15b is given by:

$$N = nN_s$$

when n is the number of amplifiers in the path.

$$\text{Further, } n = \frac{L}{\Delta S}$$

30 where  $\Delta S$  is the inter-amplifier spacing and L is the total path length.

Also we have

$$P_2 = P_{1/G}$$

where P<sub>2</sub> is the power at the input of the regenerator 35 15b.

Hence we have

$$\frac{P_2}{N} = \frac{P_1}{G} \cdot \frac{S}{LN_s}$$

but the gain G is equal to  $\exp\{-\alpha S\}$  where  $\alpha$  is the fibre 40 loss, typically 0.2dB per kilometre;

$$\text{i.e. } S \cdot \exp\{-\alpha S\} = L \cdot \frac{(P_2) N_s}{(N) P_1}$$

Solution of this equation gives the required inter-amplifier spacing for a particular span length L and for 45 a particular signal to noise ratio.

The ratio P<sub>2</sub>/N is determined by the system coding/decision circuitry and N<sub>s</sub> depends on the amplifier design.

The inter-amplifier spacing may be increased by 50 the use of forward error correcting coding techniques which reduce the bit error rate and improve the signal to noise ratio. This effect is illustrated in Fig. 4 which shows the typical relationship between amplifier spacing and system length for uncoded transmission (curve B) and forward error corrected transmission (curve A). In practice the improvement achieved will depend on the complexity of the code. There will in general be a trade-off between code complexity and

the cost of providing amplifiers.

It will be appreciated that the transmission path or span discussed above is effectively a subsystem of a larger transmission path, or in some applications a single span may be used as a medium haul path. The arrangement has the advantage that it can provide a standard subsystem e.g. of about 1000Km in length which is usable on all routes, an appropriate number of such subsystems being concatenated to achieve the desired transmission distance.

It will also be appreciated that it is necessary to provide a means of supervision of the system e.g. for fault detection so that remedial action may be taken. In particular it is necessary to supervise the operation of both the regenerators and amplifiers. The regenerators may be supervised by conventional techniques over a supervisory channel, but supervision of the amplifiers must take account of the periodic conversion of the information carrying optical signals into electrical signals for processing by the regenerators.

A suitable supervisory technique is illustrated in Fig. 5 of the drawings. This shows a system in which regeneration of the optical signals carrying communications traffic is provided by 3R regenerators 45. This communications traffic is carried on the optical path at a first wavelength  $\lambda_1$ , (or a set of wavelengths), and the supervisory channel is carried at a further wavelength  $\lambda_2$ . At the input of each regenerator 45, the supervisory channel is filtered off by a wavelength demultiplexer 46 and is fed to a regenerator device 47 comprising a photodetector and an electronic amplifier. The output of the regenerator device 47 is fed to the output side of the regenerator 45 for reconversion to corresponding light signals of wavelength  $\lambda_2$  for retransmission to the fibre path. The optical amplifier signals thus have an effectively transparent path through the system.

An alternative arrangement is illustrated in Fig. 6 in which the conventional 3R regenerators are replaced by simple (2R) regenerator devices 55 which regenerate and retransmit signals but which do not perform retiming of the signals. Removal of the timing requirement reduces the cost of the regenerator and also renders the system substantially independent of bit rate.

In the arrangement of Fig. 6 the supervisory signals pass effectively transparently through the system. In particular, as there is no retiming, the supervisory system may employ pulse width modulation to carry the necessary information. We have found that in the hybrid system described above retiming of signals is not critical and that the use of e.g. of a limiting amplifier in the regenerator provides sufficient clean-up of the transmitted signals. It will also be appreciated the removal of the retiming constraint allows future re-engineering of the system e.g. to accommodate high bit rates whereby to increase the traffic handling capacity of the system.

It will be understood that although the hybrid transmission system has been described with particular reference to transoceanic application it is also applicable to land line use.

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## Claims

- 10 1. An optical transmission system, including an optical fibre transmission path, means for launching optical signals into said path, means for receiving optical signals from said path, and signal regeneration means disposed at intervals along said path, characterised in that said regeneration means comprises a plurality of optical amplifiers and a significantly smaller number of optoelectronic repeaters or regenerators dispersed substantially evenly between the optical amplifiers, the number of regenerators being sufficient to maintain the signal quality along the path.
- 15 2. A transmission system as claimed in claim 1, characterised in that the number of amplifiers is between seven and ten times the number of regenerators.
- 20 3. A transmission system as claimed in claim 1 or 2, characterised in that each said regenerator provides reshaping and retransmission of said optical signals.
- 25 4. A transmission system as claimed in claim 3, and incorporating means for pulse width modulation of pulses transmitted in the system.
- 30 5. A transmission system as claimed in any one of claims 1 to 4 characterised in that each said regenerator is provided with means for processing wavelength division multiplexed signals.
- 35 6. A transmission system as claimed in any one of claims 1 to 5, characterised in that each said optical amplifier includes a laser pumped amplifying fibre element.
- 40 7. A transmission system as claimed in claim 6, characterised in that each said amplifying fibre element comprises a length of erbium doped silica fibre.
- 45 8. An optical transmission subsystem, including an input regenerator, an output regenerator, an optical fibre transmission path therebetween, and a plurality of optical amplifiers disposed substantially evenly along said path, the gain of the optical amplifier and the spacing therebetween being selected so as to achieve a predetermined signal/noise ratio at the input of the output regen-
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erator.

9. An optical transmission system comprising a concatenated arrangement of subsystems as claimed in claim 8.

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Fig.1.

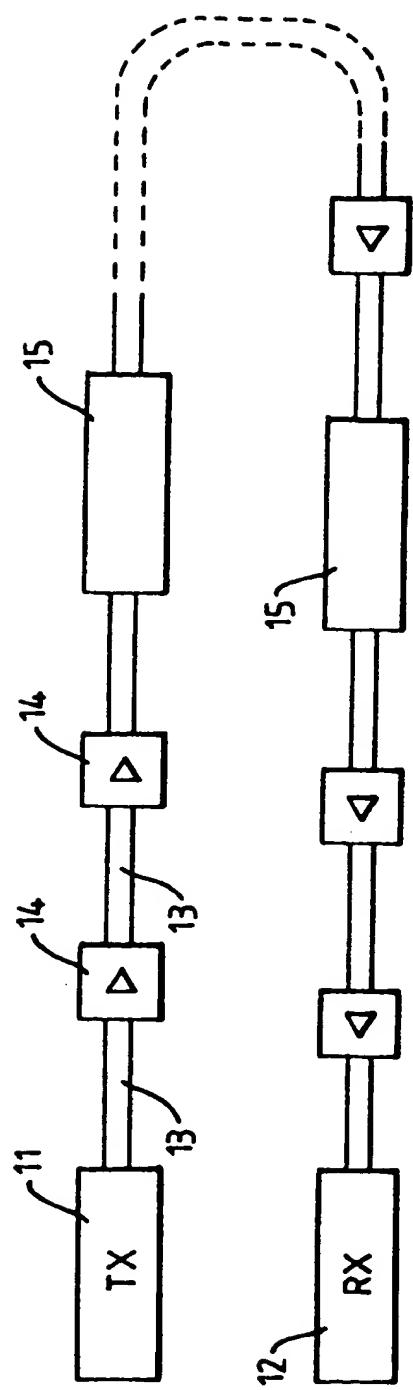
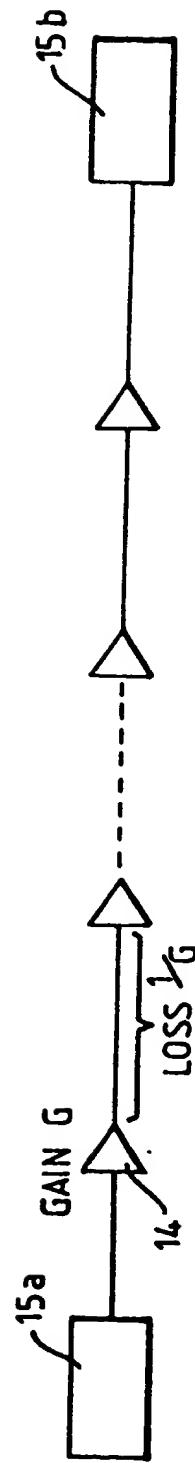


Fig.3.



# Fig.2

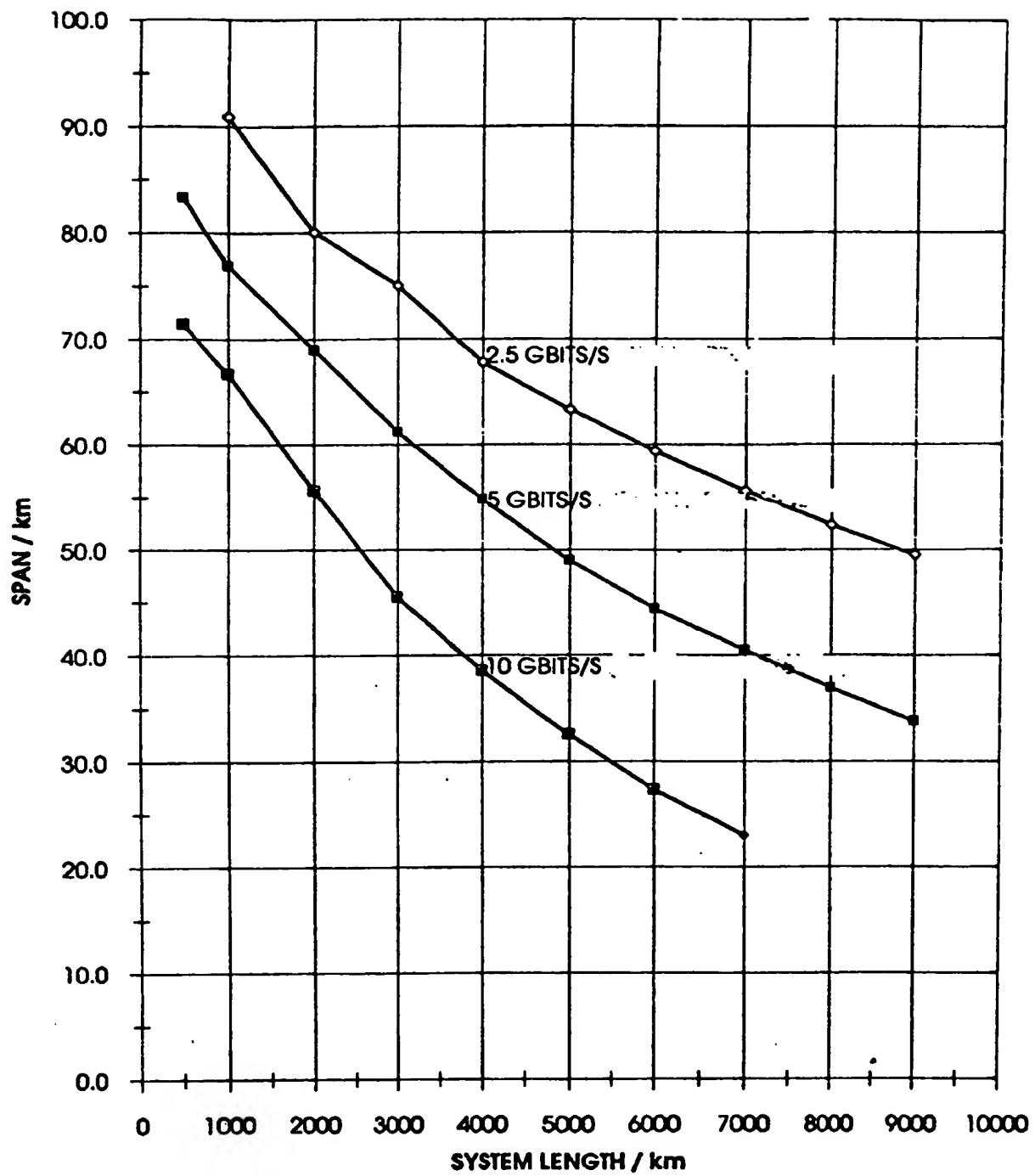
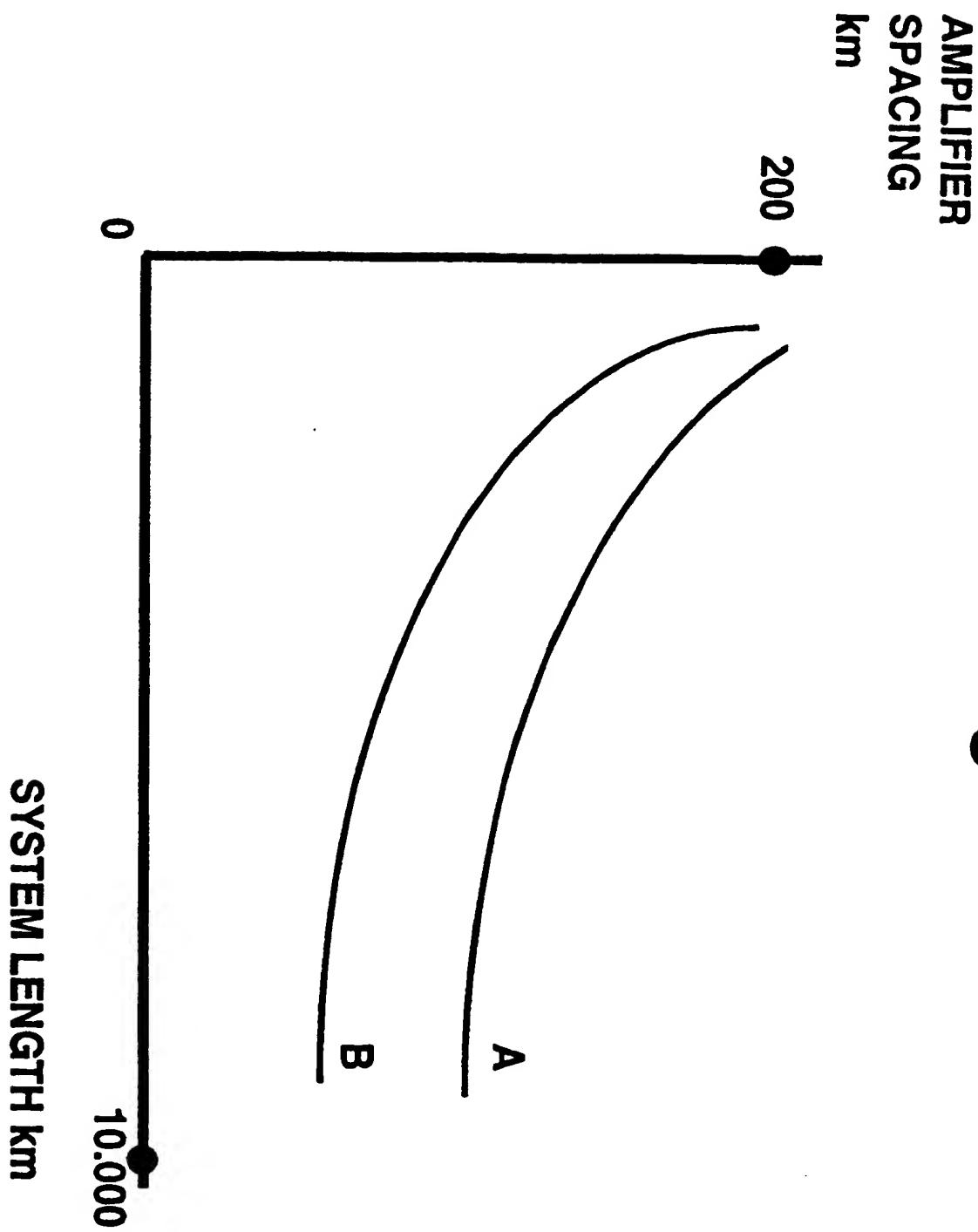


Fig.4



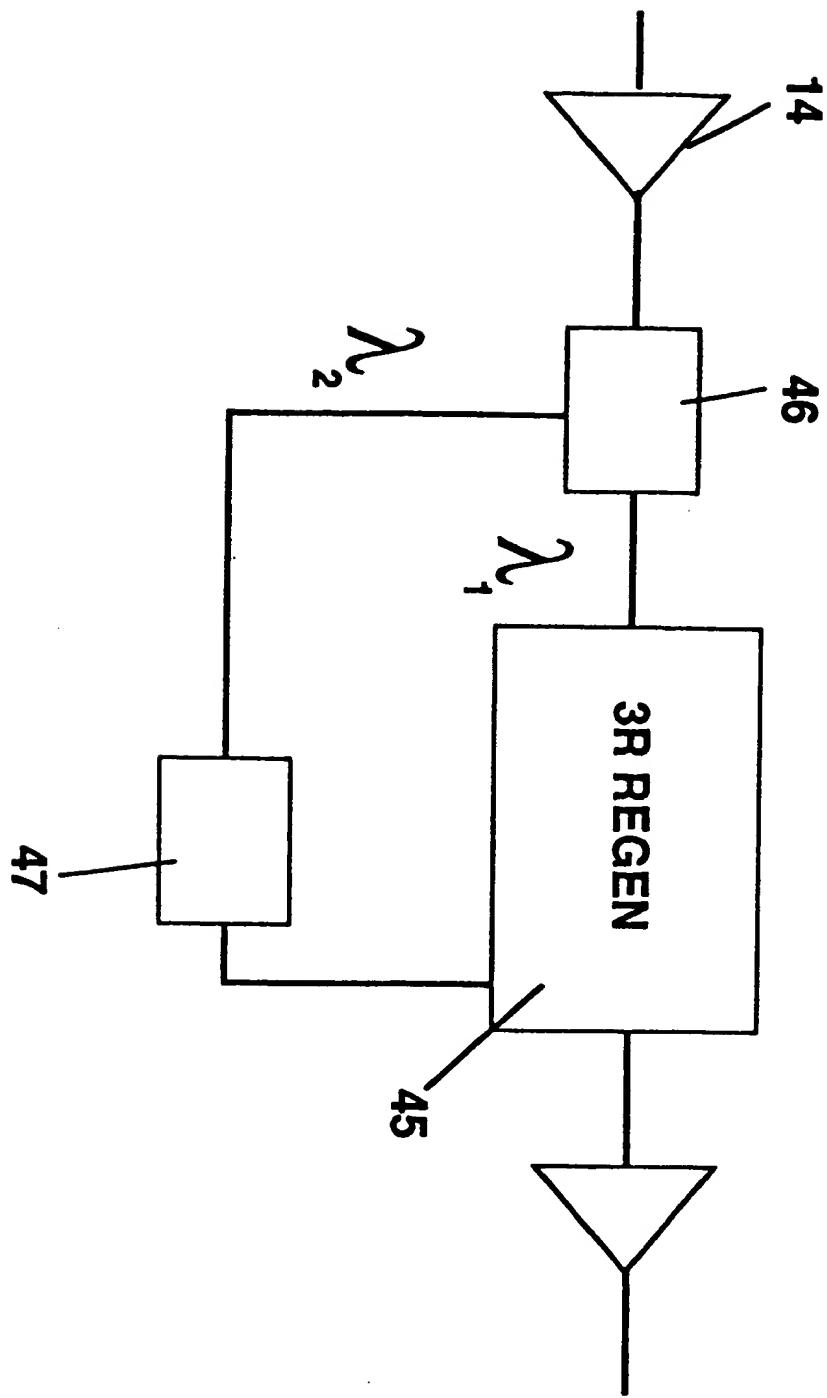


Fig.5

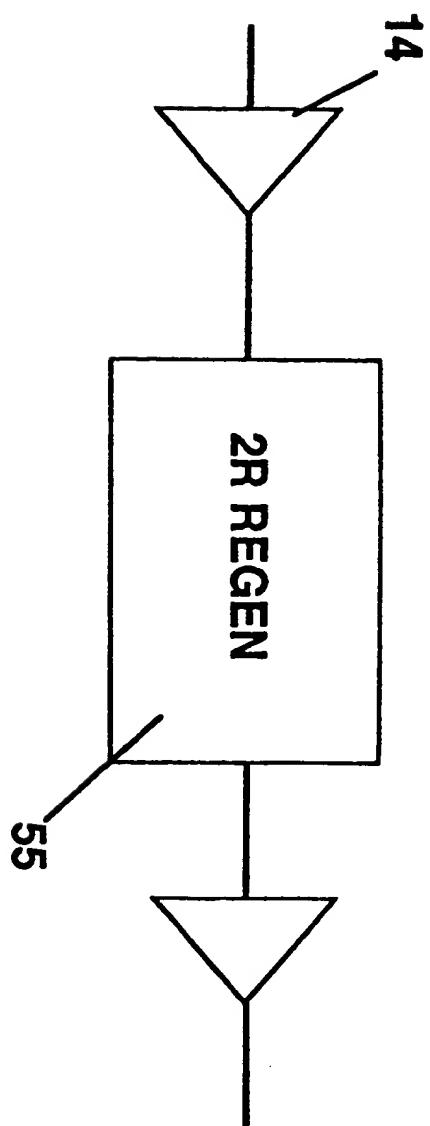


Fig.6



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## EUROPEAN SEARCH REPORT

Application Number

EP 93 30 5003

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.s)
X	IEEE JOURNAL ON SELECTED AREAS IN COMMUNICATION vol. 9, no. 5, June 1991, NEW YORK US pages 673 - 681 K.HAGIMOTO ET AL 'Over 10 Gb/s Regenerators Using Monolithic ICs for Lightwave Communication Systems' * figures 1C,22 *	1,3,6,7	H04B10/16
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Y	IEEE PHOTONICS TECHNOLOGY LETTERS vol. 2, no. 9, September 1990, NEW YORK US pages 662 - 664 D.A.FISHMAN ET AL 'A high Capacity Noncoherent FSK Lightwave Field Experiment using Er - Doped Fiber Optical Amplifiers' * page 662, left column, paragraph 1 - right column, paragraph 1; figure 1 *	5	
A	IEEE LCS. THE MAGAZINE OF LIGHTWAVE COMMUNICATION SYSTEMS vol. 1, no. 4, November 1990, NEW YORK US pages 57 - 62 K.NAKAGAWA ET AL 'Optical Amplifiers in Future Optical Communication Systems' * page 58, right column, paragraph 2 -paragraph 3; figure 5C *	1,3,6-8	TECHNICAL FIELDS SEARCHED (Int. Cl.s)
A	OPTICS LETTERS. vol. 16, no. 14, 15 July 1991, NEW YORK US pages 1116 - 1118 M.N.ISLAM ET AL 'All-optical timing restoration using a Hybrid time-domain chirp switch' * page 1118, right column, paragraph 3 *	1,3,6-8	H04B H01S
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The present search report has been drawn up for all claims			
Place of search	Date of completion of the search	Examiner	
THE HAGUE	04 OCTOBER 1993	GOUDELIS M.	
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